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P78-2 Engineering Overview

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Data from the P78-2 spacecraft are being used in verifying and validating analytical tools being developed for the design of spacecraft, such as NASCAP, for updating Military Standard 1541, for investigation of materials contamination, and for a study of the physics of charging. The analysis of this data has already resulted in changes in laboratory testing procedures, in a better understanding of some properties of materials exposed to the space environment, and in some insight into the EMI caused by discharges on → cont

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cont spacecraft in a plasma environment. Some examples of early results from the engineering experiments are presented.

SUMMARY

The engineering experiments on P78-2 are providing new results in three general areas: potentials on materials; EMI; and materials degradation. This data is being used for evaluation of materials and spacecraft design and for validation of several models generated as part of the SCATHA program. Additionally, they are being used to investigate the physics of charging and to assist in the investigation of anomalies on operational spacecraft. The data base that already exists is probably adequate to satisfy the original intent of the program (to establish charging as a mechanism for producing anomalies and to study the physics of the process) and to update the Military Standard 1541. However, continued operation of the P78-2 vehicle would permit obtaining long term data bases on materials degradation and would provide invaluable data for anomaly investigation.

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FIGURES (Continued)

INTRODUCTION

In the original Spacecraft Charging at High Altitude program, the major thrust was directed at laboratory studies and the generation of analytical tools (models) which could describe the charging process, discharges, and EMI coupling into the vehicle and its subsystems. The P78-2 experiment payload, and the data derived therefrom, was relegated to a secondary role; justifiably so, since delays associated with the design and construction of a space payload, the risk involved in a launch, and the possibility of loss of funding at any point could not be allowed to jeopardize the entire program. However, with the successful launch of the P78-2 vehicle and the extremely successful operation of the experiments in orbit, coupled with major progress in the ground-based portions of the program, the data obtained by the P78-2 payload has assumed a much more significant role in the SCATHA program.

Validation and verification of models constructed in earlier phases of the program, such as NASCAP, determination of materials behavior in orbit, characterization of EMI, and measurement of plasma parameters have gained equal importance with or overshadowed the original purpose of the P78-2 engineering experiments: to establish spacecraft charging as a viable mechanism for the production of orbital operation anomalies, to characterize charging, to quantify several parameters associated with it, and to study the properties of the space environment producing it. Figure 1 graphically depicts the interrelationships between the P78-2 data set and the other elements of the SCATHA program. Because the SCATHA program was relatively mature by the time P78-2 orbital data production began, the data are having a major impact only in the validation of ground test procedures, in model verification, in the update of Military Standard 1541, and in anomaly investigations.

Much of the credit for the versatility of the data from P78-2 must go to the balanced complement of instruments incorporated in the mission. The vehicle combined two missions into one payload: SCATHA and PIE. The second, the Plasma Interaction Experiment, provides a considerably more comprehensive description of the plasma environment than would have been available from only the SCATHA mission instruments. In return, the engineering instruments, including the Electron and Ion Beam systems, have provided accessory information of value in interpreting the data from the PIE experiments and have even enabled special experiments to be performed.

In this presentation, we will briefly discuss the engineering experiments and the uses to which their data are being put and then go into some details of the analyses, results, and accessory laboratory data being obtained to assist in the interpretation of the on-orbit data.

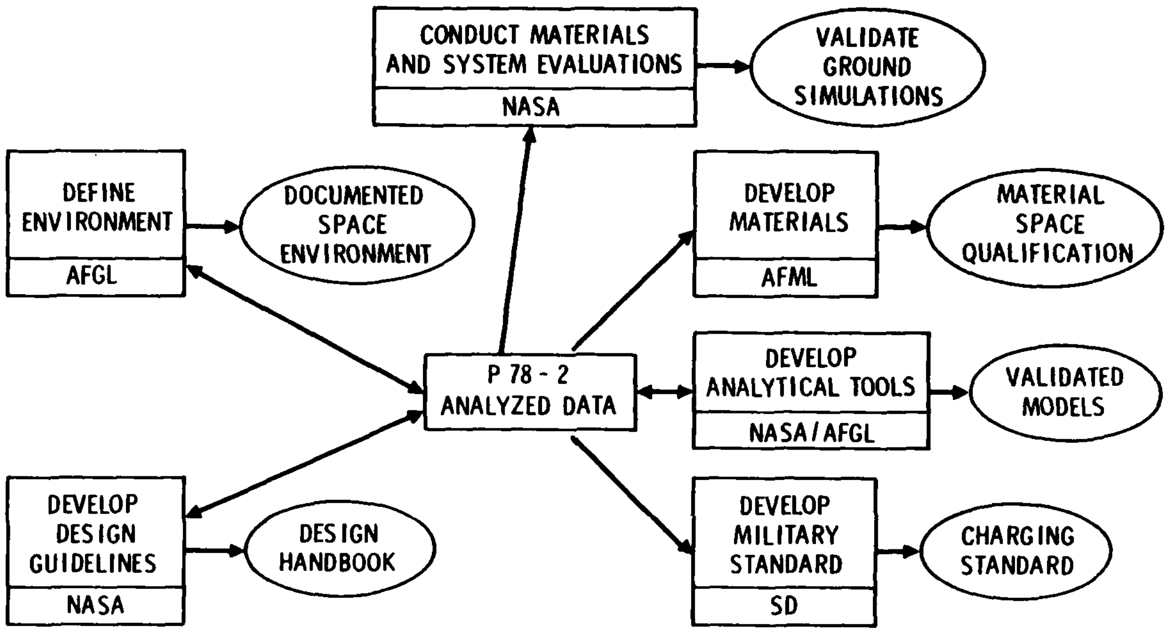

Fig. 1. The interrelationship between the P78-2 data and the various segments of the SCATHA program. The major impact of the P78-2 data is expected to be in model validation and the charging standard.

THE ENGINEERING EXPERIMENTS

The P78-2 spacecraft and payloads have been described earlier (ref. 1). A subset of these payloads, listed in table 1, are considered strictly engineering experiments and as such are the subject of this paper. The other experiments, especially SC3 (Energetic Electrons) and SC11 (Magnetometer) have engineering applications or provide accessory data required for proper interpretation of the engineering experiments data but will not be considered here further. The role of energetic electrons in spacecraft charging has been discussed earlier (ref. 2). SC4 differs from the other engineering experiments in that it is an active experiment. As such, its operations and the resulting interactions between the spacecraft and the plasma are quite complex, with much of the physics of these interactions poorly understood. Its full utility for engineering purposes awaits a more thorough understanding of these physical processes. An analysis of Electron Beam operations on P78-2 will be presented later (ref. 3).

The uses to which the data from the remaining engineering experiments are being put are outlined in table 2. Basically, there are five categories of use: model validation and verification; the Military Standard 1541 update; materials properties and contamination; the physics of the charging process; and anomaly investigation. The latter is aimed at determining whether charging played a part in an anomaly on an operational spacecraft and, if so, whether it was a surface charging event or a deep dielectric charging event. The number of users of data at this stage appears to be large, but the amount of data required by each is quite small for most uses. The primary users are the NASA Lewis Research Center, where a lot of work is being done on validating NASCAP, and Air Force Space Division (including The Aerospace Corporation) where Military Standard 1541 is being updated and where materials charging properties, contamination, EMI, and environmental data are utilized for vehicle design evaluation and anomaly investigation. As part of this overview, we shall briefly discuss the engineering instrumentation and present some preliminary results from them.

SATELLITE SURFACE POTENTIAL MONITOR

Figure 2 presents schematically the method of measurement of the surface potential of materials which was used in the SC1-1, 2, 3 instruments. A common mounting method was used for all of the sample materials, listed in table 3. The system measures the sample potential which projects through the sample to the electrostatic field sensor, i.e., a back-side measurement of the surface potential. Details of the operation and calibration of this instrument were presented at the 1978 Spacecraft Charging Technology Conference (ref. 4) and will not be repeated here. The ability to measure the potential on the surface

Table 1. P78-2 Engineering Experiments

STP 78-2 DESIGNATION	TITLE	PRINCIPAL INVESTIGATOR
SC1-1, 2, 3	SATELLITE SURFACE POTENTIAL MONITOR	P. F. MIZERA AEROSPACE CORPORATION
SC1-7 -8A -8B	RF ANALYZER VLF ANALYZER PULSE ANALYZER	H. C. KOONS AEROSPACE CORPORATION
SC2-1, 2, 3	SHEATH ELECTRIC FIELDS	J. F. FENNELL AEROSPACE CORPORATION
SC4-1, 2	ELECTRON AND ION BEAMS SYSTEM	H. A. COHEN AFGL
ML12-3, 4 -6, 7	THERMAL CONTROL COATINGS QUARTZ CRYSTAL MICROBALANCE	D. F. HALL AEROSPACE CORPORATION
TPM	TRANSIENT PULSE MONITOR	R. C. ADAMO SRI, INC

Table 2. Uses of the P78-2 Engineering Data

DATA SET	RECIPIENT	USES
SSPM	AFGL	NASCAP V&V; SC4-1, 2 OPERATIONS ANALYSIS
	NASA/LeRC	NASCAP V&V
	S^3	NASCAP V&V
	AFSD	ANOMALY INVESTIGATIONS; MATERIALS SELECTION
SC1-7, 8A, 8B	SAI	MIL STD 1541 UPDATE
	JAYCOR	TINKSAT TESTS; DISCHARGE MODEL
	IRT	SCATSAT TESTS; COUPLING MODEL
	SRI	TPM ANALYSIS
SC2-1, 2, 3	AFSD	CHARGING PHYSICS (with SSPM)
	AFGL	ATLAS; SHEATH MODEL
	S^3	NASCAP V&V (with SC5, SC9)
	NASA/LeRC	NASCAP V&V (with SC5, SC9)
TPM	SAI	MIL STD 1541 UPDATE
	AFSD	SC1-8B ANALYSIS
ML12	AFML	MATERIALS PROPERTIES/CONTAMINATION
	AFSD	CONTAMINATION

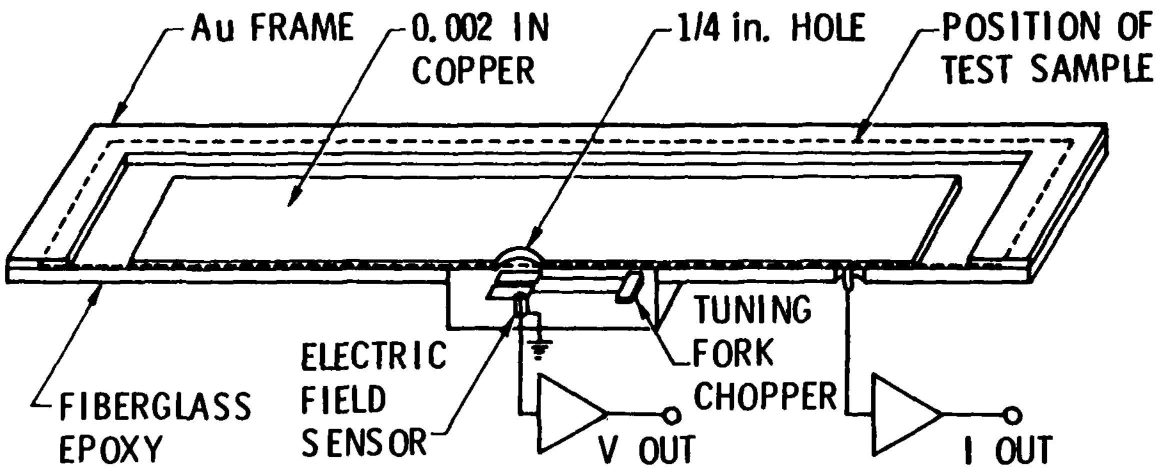

Fig. 2. Method of mounting samples and measuring potential and bulk current on the Satellite Surface Potential Monitor. The potential is measured through the bulk of the sample.

Table 3. SSPM Sample Material and Location

SAMPLE POSITION	SC1-1	SC1-2	SC1-3[a]
1	ALUMINIZED KAPTON	ALUMINIZED[b] KAPTON	ALUMINIZED KAPTON
2	OSR[c]	ALUMINIZED KAPTON	SILVERED TEFLON
3	OSR	REFERENCE BAND	QUARTZ FABRIC
4	GOLD	REFERENCE BAND	GOLD / ALUMINIZED KAPTON

a) On top of spacecraft
b) 125 mil hole through sample
c) Grounded to spacecraft chassis

while also measuring the current conducted through the sample to the copper collecting surface on the substrate permits direct measurement of the bulk conductivity of the sample while in orbit. Thus, one may observe changes in this important parameter as a result of exposure to the space environment.

Data from the SSPM are being used to validate NASCAP at various facilities: at NASA LeRC, which has the responsibility for developing a charging analysis program; at Systems, Science and Software, Inc. where the NASCAP code was developed; and at the Air Force Geophysics Laboratory, which has the responsibility for developing a sheath model (which is being satisfied by some of the physics embedded in NASCAP). For these evaluations of NASCAP, the P78-2 geometry, with materials properties of those actually used on the vehicle, is input to the program. The environment used in the calculation is an analytic representation of the actual environment measured. The goal of the test run is to calculate potentials similar to those actually measured on test samples and on the vehicle frame. Results of some of those test runs are presented in detail later on in this volume in the section on analytical modeling. In general, the qualitative results appear to be good, especially with respect to prediction of electrical stress points. The quantitative failures which occur are undoubtedly due primarily to an incomplete definition of materials properties. A secondary cause may be an incomplete definition of the plasma environment. Studies incorporating SC2 plasma data and SSPM potential data indicate that the angular distribution of the plasma flux constituants may at times be a crucial factor (ref. 5).

The properties of materials which are probably incompletely defined are the secondary emission coefficients (especially as related to the angle of incidence of the incoming particle) and the bulk conductivity. One of the reasons for this incomplete definition of materials properties is the fact that the properties change upon continued exposure to the space environment. Kapton is a good example. Figure 3 shows the bulk current density as a function of surface voltage for the 1-1 (table 3) sample. The data points labeled "before exposure to radiation" were obtained in the laboratory on a virgin sample, exposed to an electron beam in the dark. After exposure to simulated solar illumination, the "after exposure" data were obtained at three beam intensities. This was the expected behavior, based on earlier tests of Kapton (ref. 6). In those tests, the samples returned to their low conductivity state after being returned to atmospheric conditions.

Data from an early charging event in orbit, on 28 March 1979, produced bulk conductivity results as would be expected on the basis of exposure to solar illumination in orbit. However, continued exposure to solar UV without restoration of the atmospheric conditions (as occurs in laboratory testing) results in a cumulative effect on the bulk conductivity of Kapton. Figure 3 shows that by June 1980 the 1-1 Kapton sample has become a rather good semiconductor and does not charge above 50 volts even in an extreme charging environment. Incorporation of Kapton properties into a calculation as complex as the NASCAP code becomes very difficult when those properties are changing as radically as this.

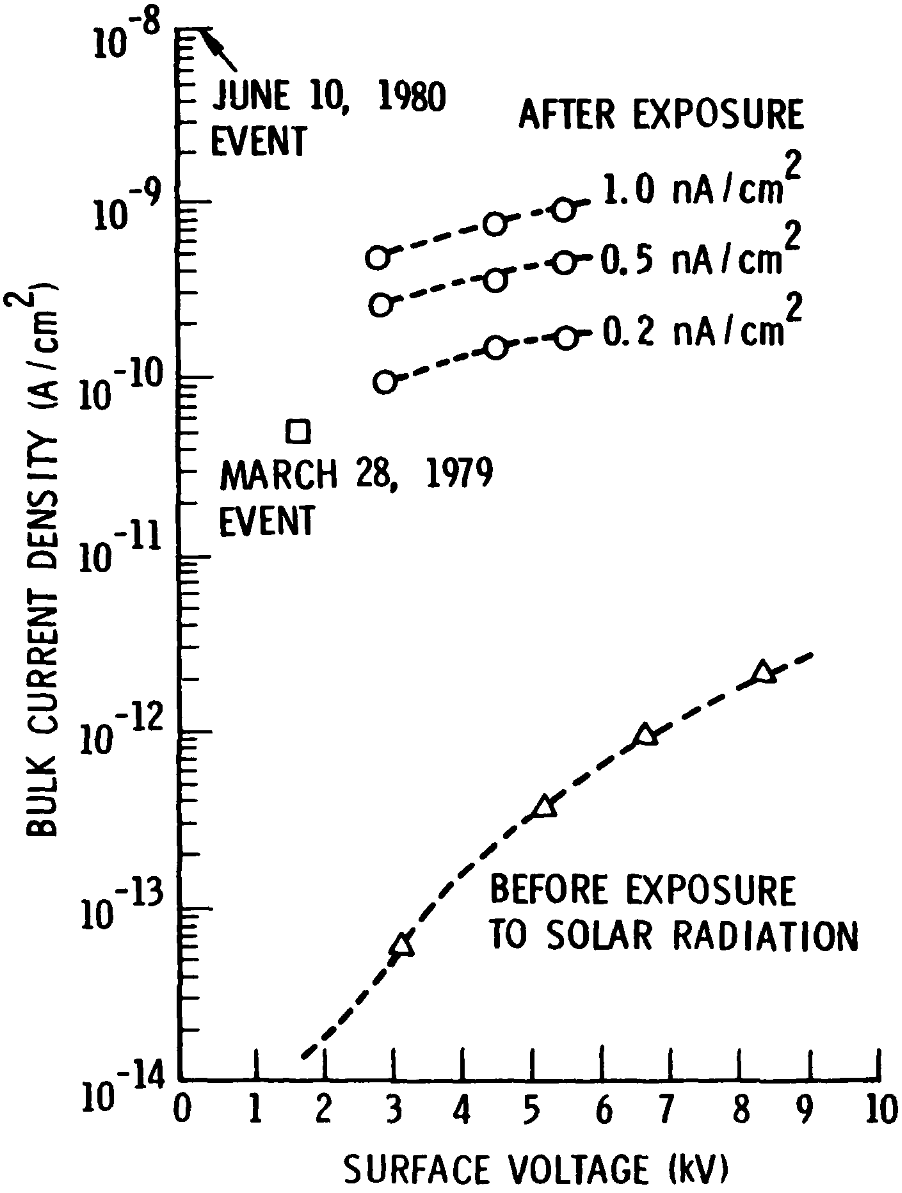

Fig. 3. Bulk current density measured on the Kapton 1-1 sample prior to flight and in orbit. By June 10, 1980 the sample would no longer support a large voltage due to cumulative effects in the solar-induced photoconductivity.

In addition to using the SSPM data for validation of the NASCAP model, surveys are being made in an attempt to parameterize the charging environment and the response of different materials on a statistical basis. Figure 4 shows the approach. In this plot, the probability, P, of the potential of the Kapton 1-1 sample exceeding a voltage V (with respect to the vehicle frame) is presented for two local time sectors. The data clearly show more charging activity in the post-midnight sector than in the pre-midnight sector, as would be expected. At this stage of the analysis, it is hazardous to draw any quantitative conclusions from this data set, for reasons to be discussed below. The intent of a statistical approach such as this is to furnish the design community with a relative evaluation of the charging behavior of selected materials in the charging environment which will be encountered in orbit.

The shortcomings on the data set used to produce figure 4 deserve discussion since they may be applicable to other data sets obtained either in the lab or in space. First of all, the materials properties of the Kapton sample were changing, due to exposure to solar UV, during the time this data was being acquired. Thus, for a given charging environment, the potential to which the sample charged decreased as a function of time. For this or other materials, it is also possible that penetration by energetic electrons produces permanent changes in bulk conductivity. Finally, exposure to sunlight, deposition of contaminants, erosion, etc., can produce changes in the secondary emission ratio as a function of time. A statistical approach is not completely valid unless the properties remain essentially constant.

A second major problem is the fact that all of the data were obtained over a three month period. To get a good statistical representation of the environment, data should be collected over a major portion of a solar cycle, since the charging environment is ultimately produced by solar activity. Hence, a three month period is unlikely to represent the environment correctly. A third major difficulty is the assumption that all data points can be treated as statistically independent data samples. The data used in this survey was obtained by extracting the maximum potential observed during each one-minute data acquisition period that the vehicle was in the proper local time sector. Obviously, the correlation time for charging events is much greater than one minute. If a sample shows the potential to be, say, 2000 volts, the preceding and following samples are unlikely to be far different. In order to properly treat data such as this with a statistical approach, one must determine the correlation length (in time) of a charging event. This has not yet been done. Once one knows what the correlation length is, one can assure statistical independence by using that correlation length for the sampling period. However, even definition of correlation length may be difficult for this phenomenon: it may vary for different materials, different vehicles, and different magnetospheric conditions.

The equation given in figure 4 assumes that one can extrapolate the portion of the curve above 500 volts. Again, there is a serious fallacy here if the extrapolation is carried too far: the sample will at some point break

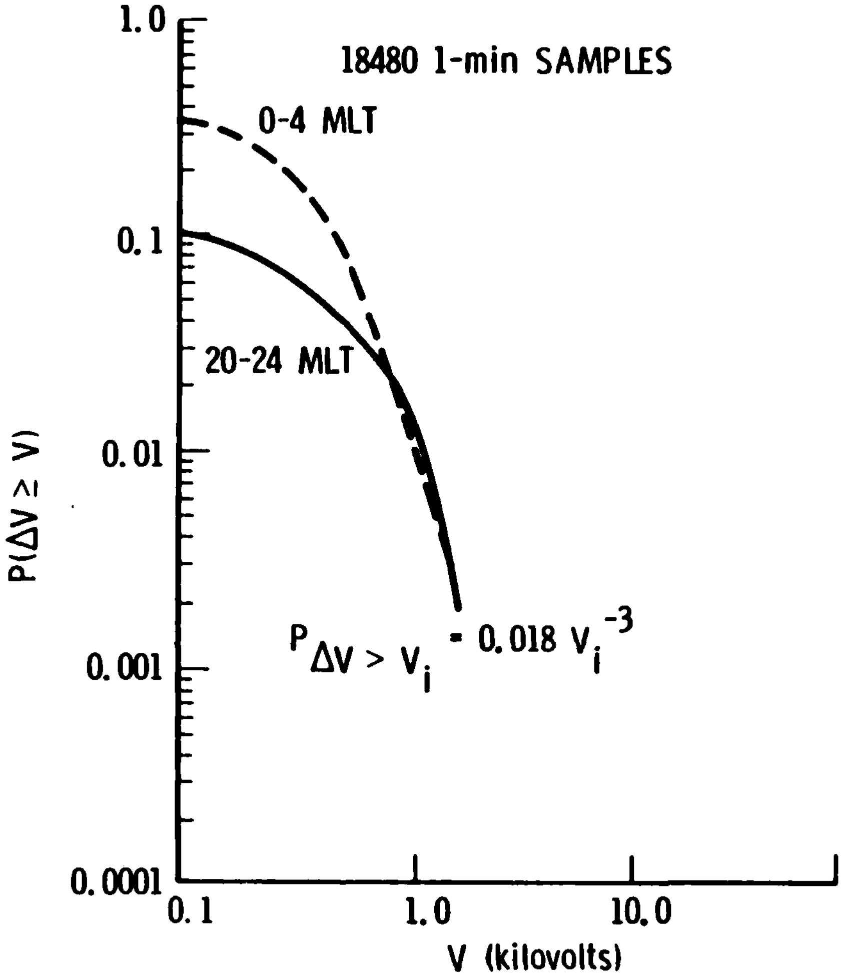

Fig. 4. The probability of seeing a potential greater than a given voltage on the Kapton 1-1 sample is plotted for two local time sectors. The equation is valid for this data from 500 to 2000 volts. See cautions in the text regarding extrapolations and interpretations of this figure.

down, limiting the potential. Non-linear conductivity effects of a less spectacular nature will also come into play at some point. Because of the complex behavior of some of these materials, a simple approach may be satisfactory for the design engineer: assume the behavior already observed in orbit represents the behavior that will occur in the future for that material. This works only if a compendium of materials behavior is available for various materials and a sufficiently wide range of orbital environments. Lacking that, analyses must be made (again assuming that the analytical models, the environments, and the materials properties used are valid).

Initial analysis of orbital data disclosed significant discrepancies between the behavior observed in the laboratory calibrations of the SSPM and the response in orbit. Figure 5 shows schematically the laboratory test apparatus set up at The Aerospace Corporation to investigate these discrepancies. The notable detail here is the sapphire window used for the solar simulator. Figure 6 presents Kapton data obtained during a charging event in orbit. The upper panel shows the charging profile as the Kapton rotates in and out of sunlight. When it enters shadow, the sample starts charging and then discharges as it reenters sunlight. In the original laboratory tests at LeRC, center panel, the solar simulation was deficient in UV (the window was not made of UV transmitting material) and did not completely discharge the sample when the light was turned on (to simulate rotation into and out of sunlight). As a result, the potential on the Kapton built up to the beam energy (minus the secondary emission crossover potential) in the dark and showed only slight discharging in the light. With the solar simulation used in the Aerospace test, the behavior of the test sample was very similar to that observed in space. For both the LeRC and Aerospace simulations a monoenergetic electron beam was used. Because the photoinduced conductivity does not quench immediately upon removal of the light source, the peak voltage reached by the sample is much less than beam energy.

Another significant deviation between predicted behavior and observed behavior occurred in the quartz cloth sample. Using high energy monoenergetic electron beams, silica and quartz cloth had been charged to kilovolt potentials, but the presence of lower energy electrons (a few kiloelectron volts) limited surface potentials to one or two hundred volts (ref. 7). The difficulty in getting the material to charge to higher voltages in the laboratory led to its extensive use on DSCS to prevent charge buildup. In orbit, the Astroquartz sample on the SSPM charges to higher potentials than Kapton and over 6000 volt levels have been measured. Measurements of the material in the laboratory disclosed that the material initially charges up to a high potential and then relaxes to a small value. However, as shown in figure 7, the relaxation time constant is a strong function of the input current density (ref. 8). For current densities in the range of those encountered in space, tenths to hundreds of picoamps per cm^2, these time constants are long compared to typical charging environment events. In previous laboratory tests, the current densities were in the nanoamp to microamp range. The initial excursion in voltage was treated as an experimental transient and ignored (or missed altogether).

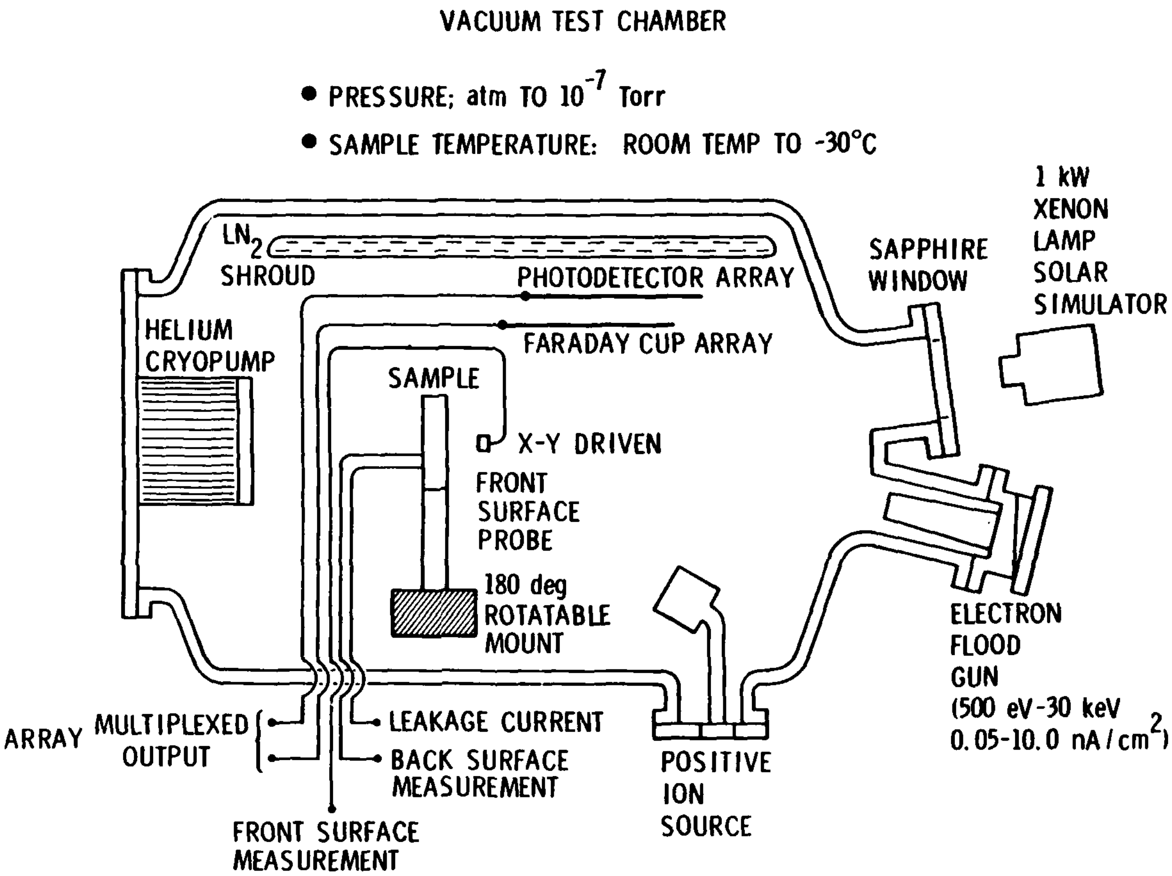

Fig. 5. Schematic diagram of the test chamber at The Aerospace Corporation which is being used to reconcile orbital SSPM data to previous measurements of materials properties at other laboratories. This facility has been modified to include a second electron gun for dual beam energy studies (not shown).

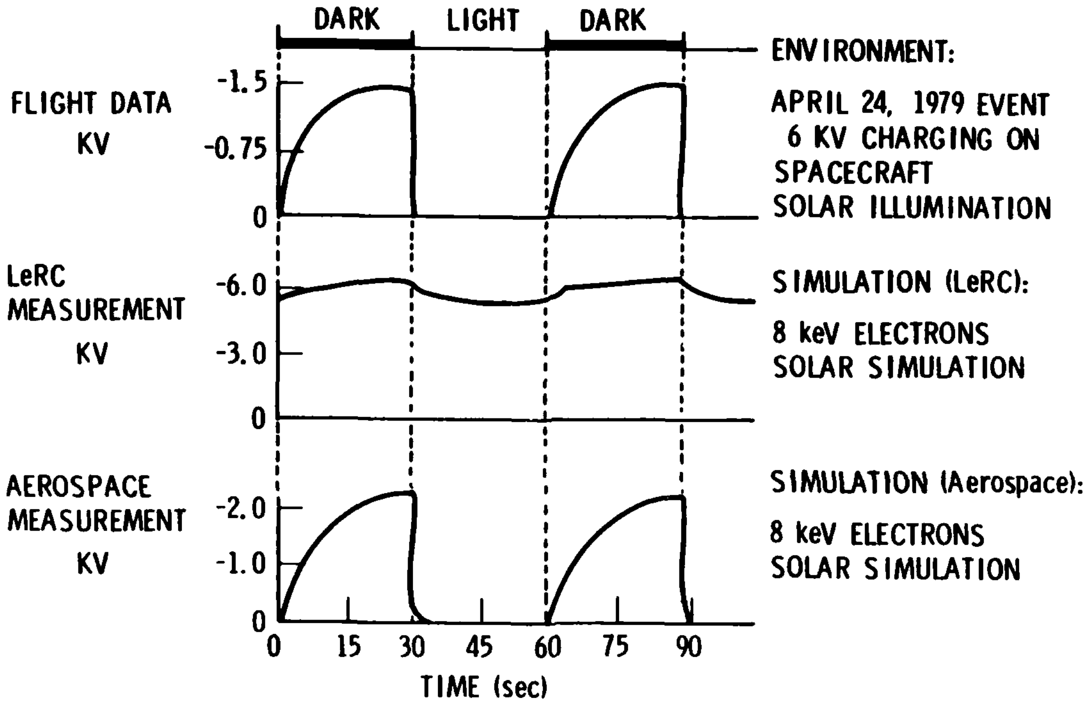

Fig. 6. Comparison of space SSPM data from the Kapton 1-1 sample with calibrations prior to flight and with tests in the chamber shown in Figure 5. UV-induced photoconductivity results in complete discharge of the sample in space and in the Aerospace simulation.

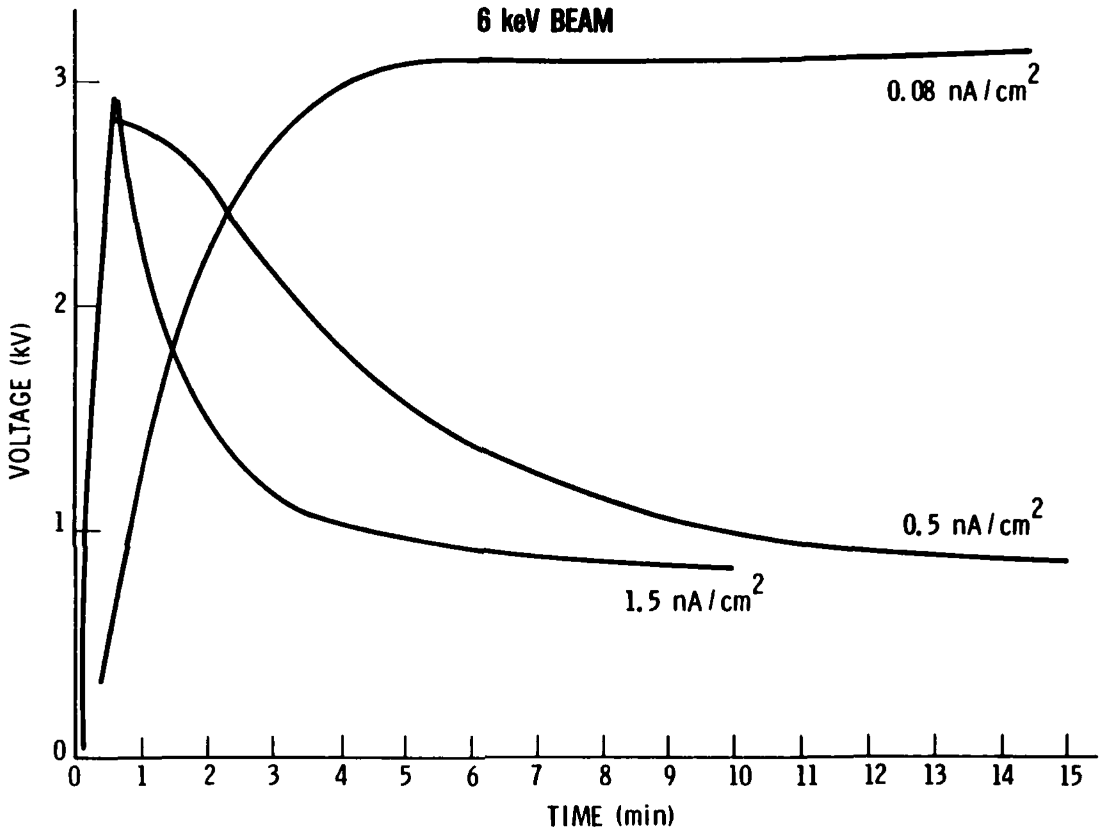

Fig. 7. These curves demonstrate the effect of current density on the relaxation time constant of quartz fabric charged by an electron beam. The 0.08 nA/cm^2 curve is representative of a space charging environment.

A low-level-of-effort laboratory program is being maintained at Aerospace to continue assisting in resolving discrepancies between the orbital SSPM data and the preconceived response to the environment. The current work is aimed at solving some of the problems in getting NASCAP predictions to agree with orbital data. The approach is to make very careful measurements of the secondary emission ratio of the SSPM materials in order to provide appropriate input constants for NASCAP. The preliminary results of this effort were presented earlier in this volume (ref. 9).

SHEATH AND CHARGING PHYSICS

The SC2-1, 2 and 3 sensors are sets of electron and ion detectors which use electrostatic deflection of analyze fluxes of particles in the energy range of about 20 eV to 20 keV. Two sets are mounted in spherical enclosures at the ends of 3-meter booms; the other set is body mounted. The spheres initially were maintained at plasma potential as part of a sheath physics experiment. Arcing induced by electron beam operations disabled portions of the spherical probe circuitry and the enclosures are now maintained at vehicle potential (ref. 3). Measurements of the sheath geometry are made by making simultaneous measurements with the three sets of sensors, all pointing in the same direction but in different portions of the particle trajectory through the sheath. Particles entering one of the sets in a sphere have not traversed the sheath region between the sphere and the vehicle body. Particles entering the body-mounted instrument have had their energy and trajectory modified by the potential between the part of the sheath at which the first sphere is located and the vehicle body. Finally, the detectors in the other sphere are observing particles which have had their trajectories modified by passing near the vehicle body. For a given potential on the body, electrons and ions will show much different behavior for this last set.

The study of the physics of charging requires simultaneous analysis of several sets of data. Figure 8 shows a preliminary step in this analysis. The upper two panels show the electron flux and the ion flux, respectively, measured by the body-mounted sensors. Lighter areas indicate higher flux densities. The data presentation starts in sunlight, as shown by repetitive bright lines in the 20 to 40 keV part of the ion spectrogram (the result of sensitivity to solar UV by the instrument which measures this part of the ion energy spectrum). Just after going in to the earth's shadow the vehicle is emersed in a hot plasma, as shown by the increase in the energy of the maximum in the electron flux (near 23.7 local time). The Kapton sample responds by charging to about 1500 volts with respect to the vehicle frame, bottom panel. The vehicle frame, too, charges as shown by the change in the ion spectrogram. The cold ambient plasma ions are accelerated by the vehicle potential and are observed at energies in excess of 4000 volts, indicating the vehicle itself has charged to this potential. Note that the Kapton maintains a differential charge with respect to the vehicle. As the vehicle comes back into sunlight,

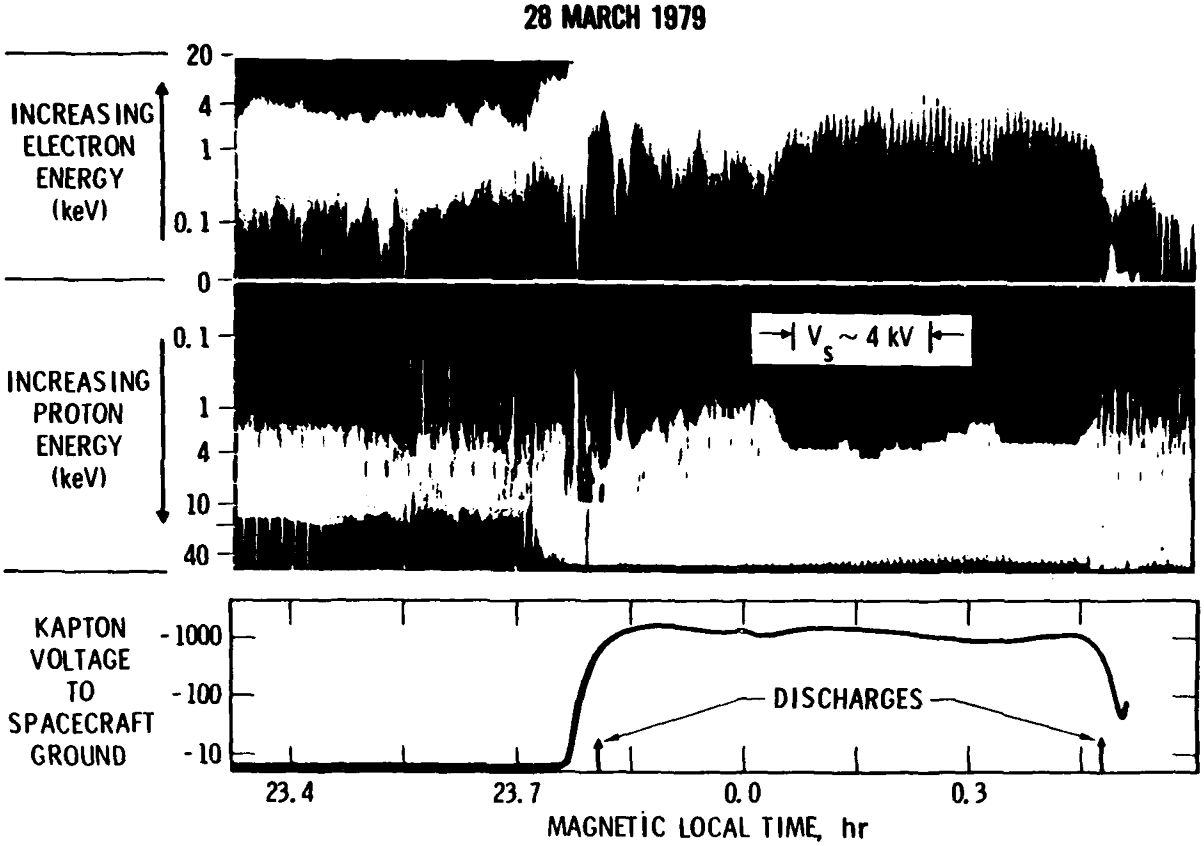

Fig. 8. Natural charging event on the P78-2 spacecraft in eclipse. The upper two panels are spectrograms of the electron and ion fluxes. The lowest panel shows the charging profile of a Kapton sample and two natural discharges detected by the Pulse Analyzer. See text for details.

evidenced by the burst of photoelectrons shown at very low energy near the right end of the upper panel, the vehicle potential returns to a low value and the Kapton sample discharges. The pulse analyzer detected discharges during the time when the vehicle was charging up and also when it was discharging, times when maximum electrical stress occurs on the vehicle (bottom panel).

The sheath physics and charging physics task is rather formidible. However, some significant results have already been extracted from the data. One of these, discussed in ref. 5, will probably result in a modification of NASCAP. It appears that differential charging, as distinguished from vehicle charging, is dependent on the angular distribution of the hot plasma particles. The hot plasma particles, unlike the cold background plasma, is frequently asymmetrically distributed.

PULSE ANALYSIS

Two experiments contribute to the study of EMI produced by discharges. One experiment, the Charging Electrical Effects Analyzer, consists of three separate instruments, each measuring a different electromagnetic phenomenon. Two of these instruments, the Very Low Frequency Analyzer and the Radio Frequency Analyzer, measure wave frequencies and amplitudes. Preliminary results from these wave analyzers were presented previously (ref. 10). The third instrument, the Pulse Analyzer, is the prime EMI detector/analyzer on P78-2. A complementary experiment, the Transient Pulse Monitor, was added late in the design of the P78-2 to supplement the data obtained by the Pulse Analyzer. The two instruments make different measurements of the same phenomenon, electrostatic discharges, and so the analyses of the two data sets are coordinated. Since virtually nothing was known about the characteristics of discharge pulses in space other than the amplitude distribution observed on cables used as sensors on a couple of previous satellites, the Pulse Analyzer was built with many of its characteristics programmable by ground command. Figure 9 is a simplified block diagram of the Pulse Analyzer. Options which are ground-commandable include: ANTENNA SELECT, which can be set to dwell on one antenna or to cycle through two or four antennae; ATTENUATOR LEVEL, which selects the overall gain through the system; THRESHOLD LEVEL, which selects the trigger level for pulse analysis; and TIME BASE, which selects linear or logarithmic spacing for pulse sampling, and if linear, the time between samples. A more detailed description of the instrument is given in ref. 10.

The great flexibility, which was required to insure having an instrument in orbit which could measure several different parameters in the appropriate ranges, has delayed getting data in the ranges most appropriate for analysis. The relative infrequency of naturally occurring discharges (an average of about one per fifteen days of data) plus a very long delay in getting the initial orbital data processed (about 9 months between launch and production processing

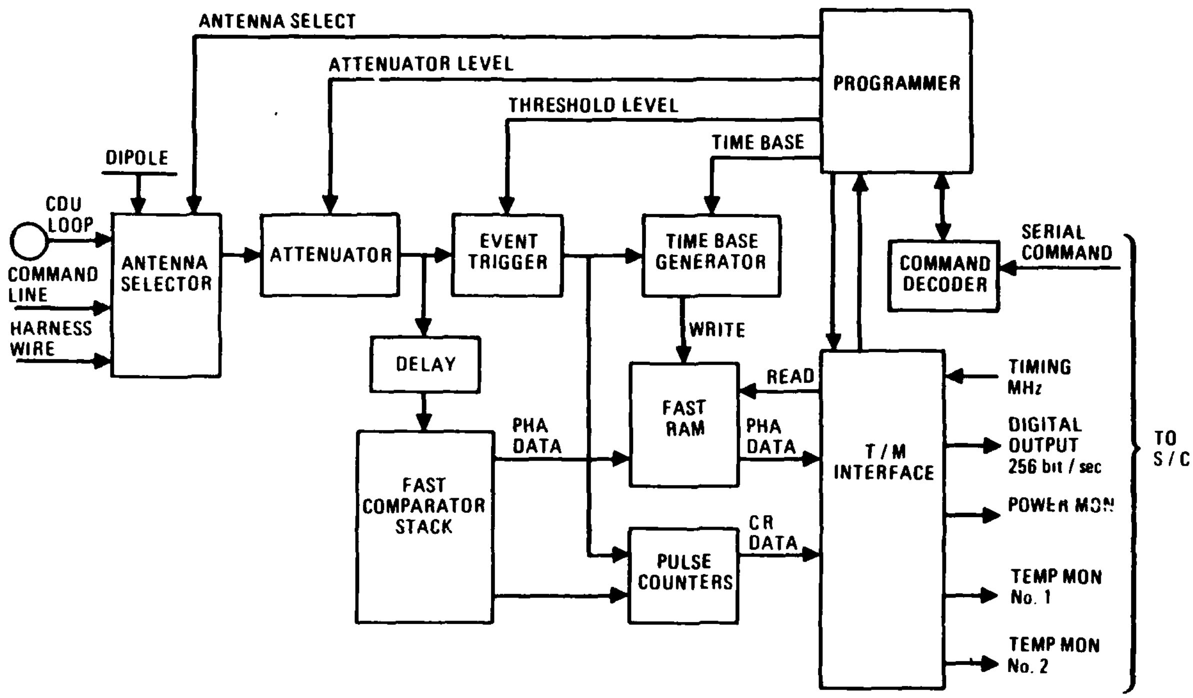

Fig. 9. Simplified block diagram of the SCI-8B Pulse Analyzer showing the flexibility of operation provided through ground commands. This flexibility was required in order to insure that the instrument would be able to make measurements of various parameters, each in the proper range, in spite of the fact that virtually nothing was known about the amplitude or frequency components of discharges prior to flight.

of orbital data) has resulted in only five pulses due to natural discharges having been sampled in the high time resolution mode (15 nanoseconds between samples) required for analytic evaluation. Other data may exist in the data pipeline which will increase this data base.

Figure 10 shows the type of analysis being performed on these high time resolution data. The sixteen pulse samples are fit with a two-frequency damped model. From the fit, the frequencies, damping factors, amplitudes, and phase angle are obtained. The upper waveform in figure 10 is the fit to a natural discharge. It cannot be called a typical discharge, since none of the five discharges analyzed to date are similar to another. The lower waveform is a fit to a pulse observed during an Electron Beam (SC4-1) operation. Most notable is the low damping factor. Details of these pulse analyses are presented elsewhere in this volume (ref. 11). Preliminary indications are that pulses contain a frequency component around 25 MHz, which is probably characteristic of the geometry of the vehicle and its sheath, and a component from a few MHz to a few tens of MHz which is probably characteristic of the discharge path itself. The future emphasis in analysis of the pulse data will be on locating discharge points and characterizing the discharge and coupling into the vehicle. This effort is being augmented by tests on a model of P78-2, SCATSAT.

In addition to the high time resolution data analysis, a larger body of data from the Pulse Analyzer is being used to determine amplitude characteristics of natural pulses. The entire data set from the Pulse Analyzer is useful for this purpose, since only a threshold measurement, not pulse sampling, is required. The TPM provides similar data but with a lower threshold set for pulse analysis. Figure 11 shows a comparison of 19 natural discharges from the Pulse Analyzer data set and about 115 pulses from the TPM. Both sensors have 50 ohm inputs. The pulse distributions from the two instruments are similar, even though the Pulse Analyzer (SC1-8B) distribution appears to be skewed to higher voltages than the TPM. This is an artifact of the data presentation. The data from the Pulse Analyzer were obtained with logarithmically spaced thresholds (only three thresholds are represented in the plot) while the TPM data is obtained with linearly spaced thresholds.

The data from the TPM shown in figure 11 has a companion set obtained from the high impedance antenna on the TPM at the same time. These pulses were all measured simultaneously on both the low and the high impedance antennae. Figure 12 presents the distribution for both of these sensors and also the ratio between the amplitudes measured on the high and low impedance antennae. The ratios vary from less than unity to over 15, with major portions being centered around ratios of five and eleven. Such data is of use in evaluating coupling models. Again, these data are discussed in more detail in following papers (refs. 11, 12).

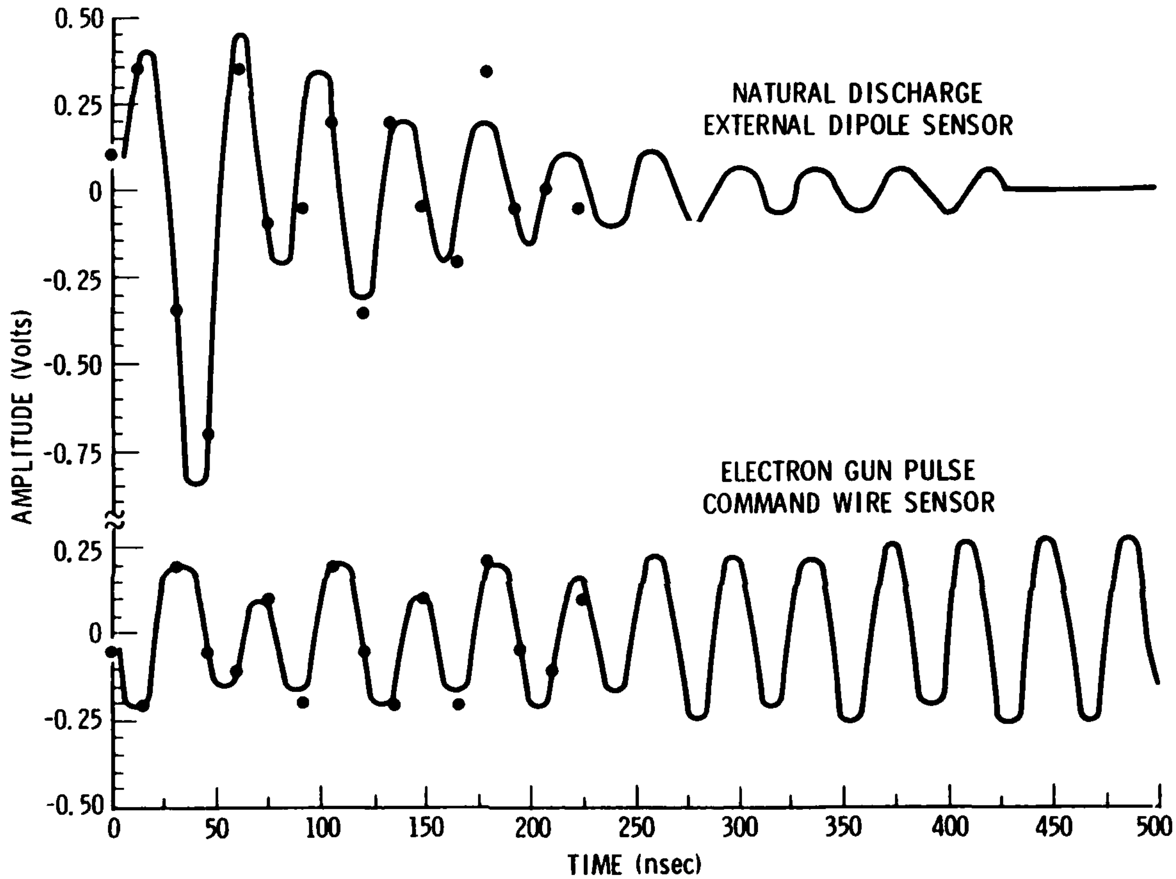

Fig. 10. Plots of the results of analysis of data from two discharges observed on the P78-2 by the SC1-8B Pulse Analyzer. The dots are the data samples at 15 nanosecond intervals. The solid lines are the best fits to the data using two frequency components with arbitrary phase and damping.

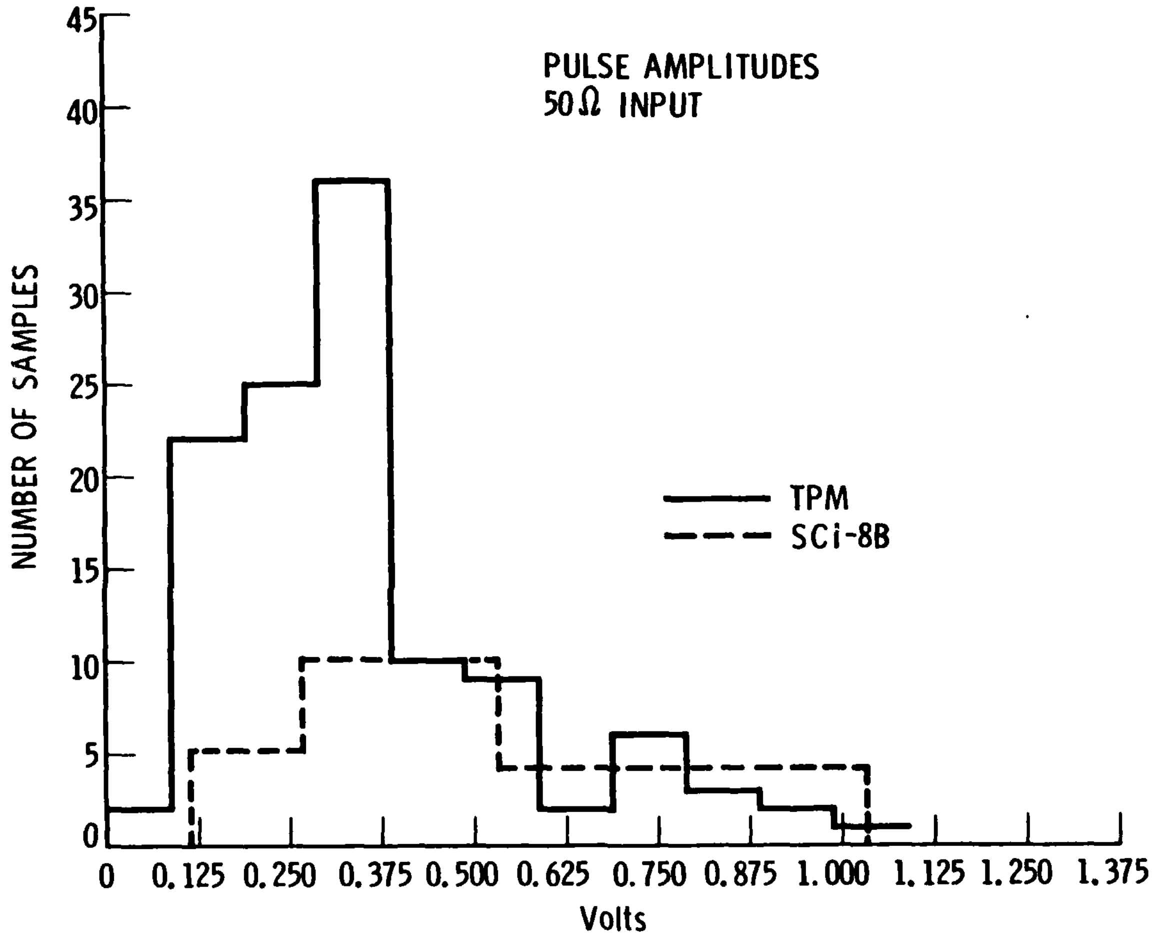

Fig. 11. Comparison of natural pulses detected by the TPM and the SCl-8B Pulse Analyzer. Distributions are equivalent, though the logarithmicly-spaced thresholds on the SCl-8B instrument appear to be skewed to higher levels.

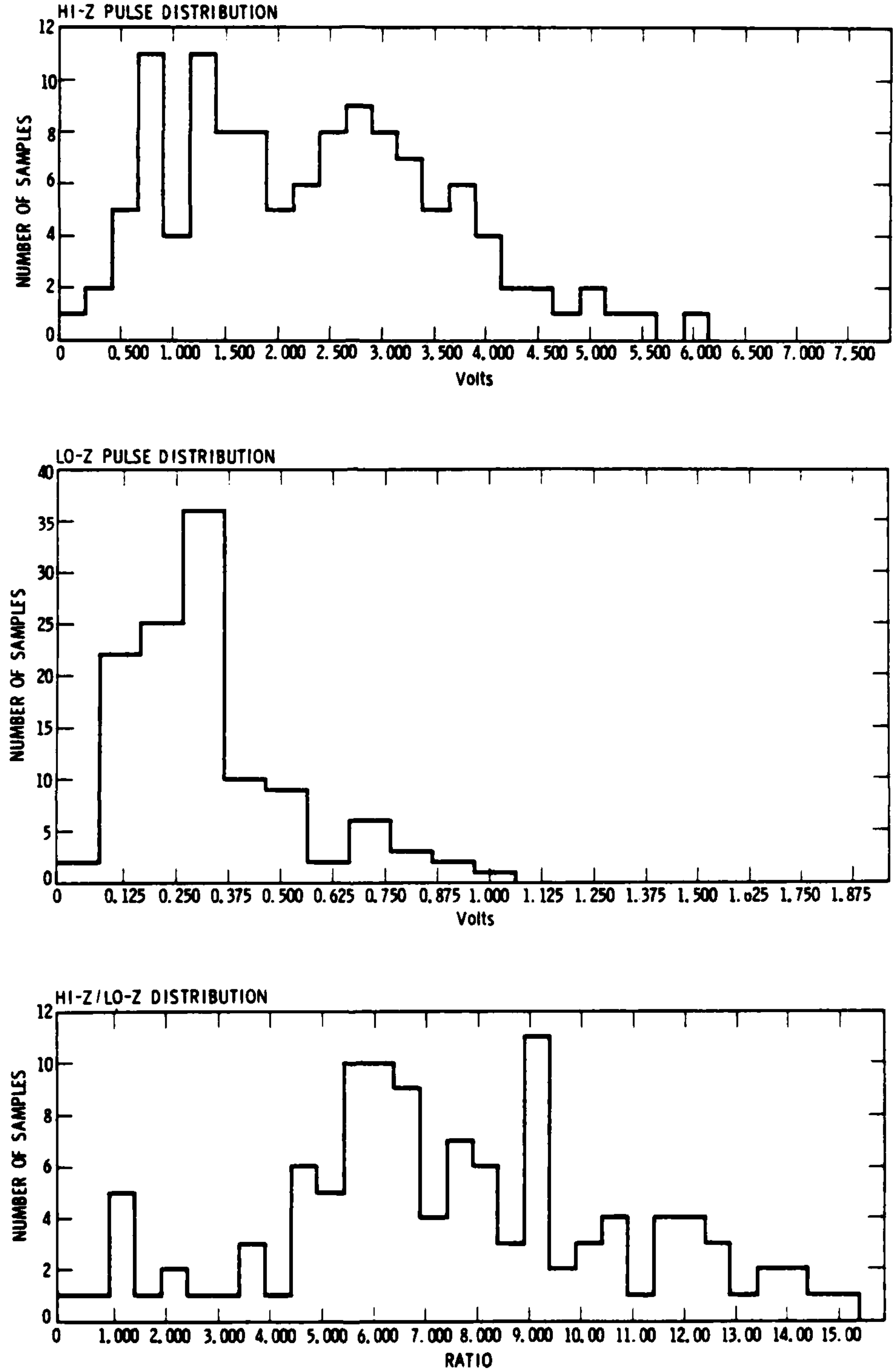

Fig. 12. Distributions of pulse amplitudes observed in the TPM high impedance and low impedance antennae. The bottom panel presents the ratio of the high-to-low measurement for the same pulse.

CONTAMINATION AND THERMAL CONTROL

In addition to the operational mode changes and electronic subsystem damage which have been blamed on spacecraft charging, degradation effects in thermal control surfaces, optical components and sensors have also been postulated to be enhanced by charging. Figure 13 presents the mechanism schematically. A molecule from the spacecraft, either outgassed or sputtered from the surface of the vehicle, is ionized by a solar photon while still in the vicinity of the vehicle. In the absence of a hot charging plasma, solar-induced photoelectron current from the vehicle normally results in a slight positive potential on the vehicle which would prevent reattraction of such an ion. If the vehicle is charged negatively, the ion can be reattracted to the vehicle if it is still within the sheath region. A thorough discussion of the experiment and some preliminary results are given in ref. 13.

Figure 14 presents some of the preliminary contamination data. The sudden increase at about 120 days is an artifact of the data reduction and analysis. At this preliminary stage of analysis, effects due to temperature changes of the sensor have not been corrected for and the response at 120 days is the result of a temperature command. The primary purpose of displaying this data is to show the requirement for long-term data acquisition on this experiment. The data are plotted on a semi-logarithmic display for ease in determining an extrapolation for long duration missions. If the primary source of contamination is outgassing of vehicle components, one would expect an exponential decay in the rate of accumulation which would result in a straight line on this display. Charging episodes, if they were infrequent and had a significant effect on the deposition rate, would show up as discrete displacements of the curve without a change in slope. If they were frequent, they would change the slope. The data of figure 14 indicate that for the first year the deposition rate was effectively linear. The derivative of this curve, which is presented in ref. 14, indicates that the rate of deposition is actually decreasing with time. It appears that the proper extrapolation of this curve will fall between the light and heavy dashed extrapolations shown on the figure. The Repelling Potential Analyzer, basically an ion trap attached in front of the Thermally-Controlled Quartz Crystal Microbalance, indicates that ions with energies up to 500 eV/charge constitute 25% of the total mass accumulation (ref. 14).

The other portion of this experiment, the Thermal Control Coatings experiment, measures changes in solar absorptivity, α_s, in a number of typical spacecraft materials. Six of the samples include heaters to provide for desorption cleaning of the sample during flight. A comprehensive description of this experiment, data derived from it, and data analysis techniques are given in ref. 15. Major results to date include measurement of changes in α_s in several materials, presented in figure 15, and the observation that the use of indium oxide on OSRs and Kapton (in order to control charging) increases the early degradation of their thermal properties. Again, figure 15 is a semi-logarithmic plot in order to easily distinguish between linearly and exponentially decreasing degradation. The time span covered by the data is still too short to determine which is occurring.

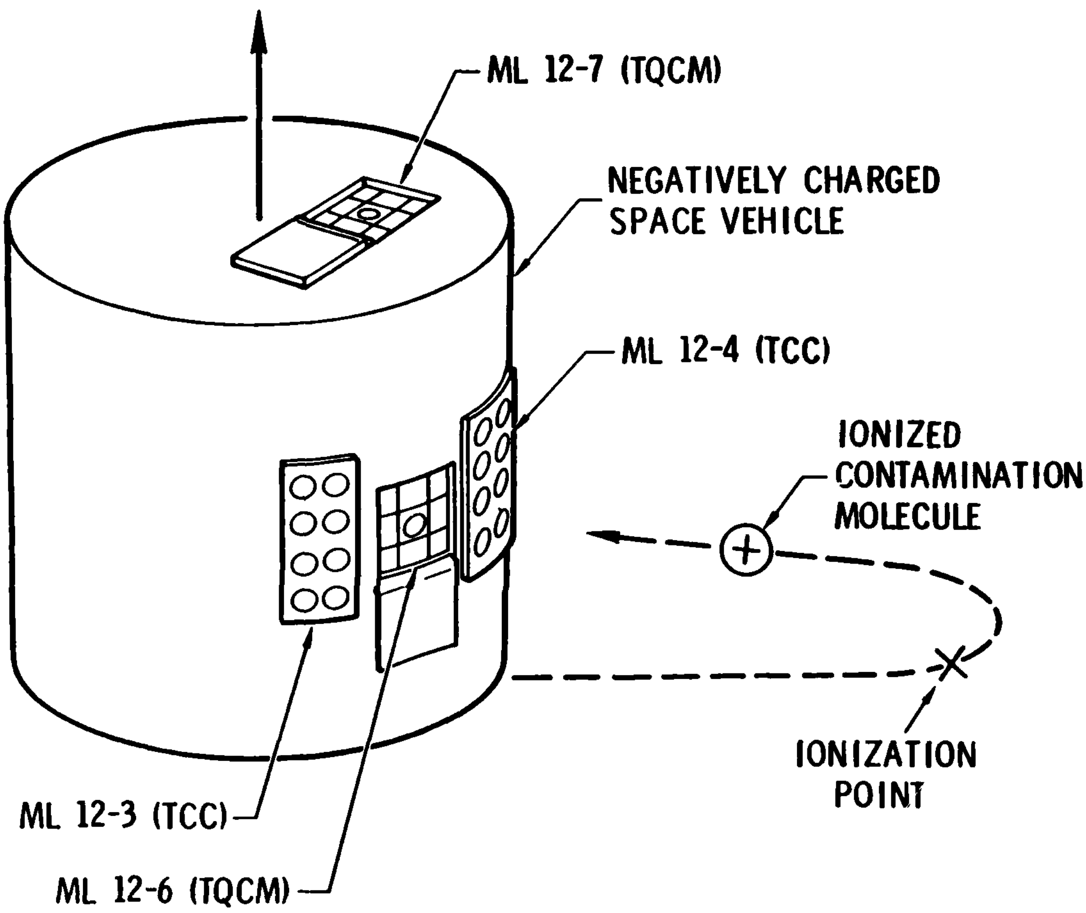

Fig. 13. Schematic diagram of the experiment to determine the effect of charging on the rate of contamination of spacecraft surfaces. A molecule emitted from the surface is ionized by solar radiation while still within the sheath region of the satellite. The ion is then attracted back to the negatively charged vehicle.

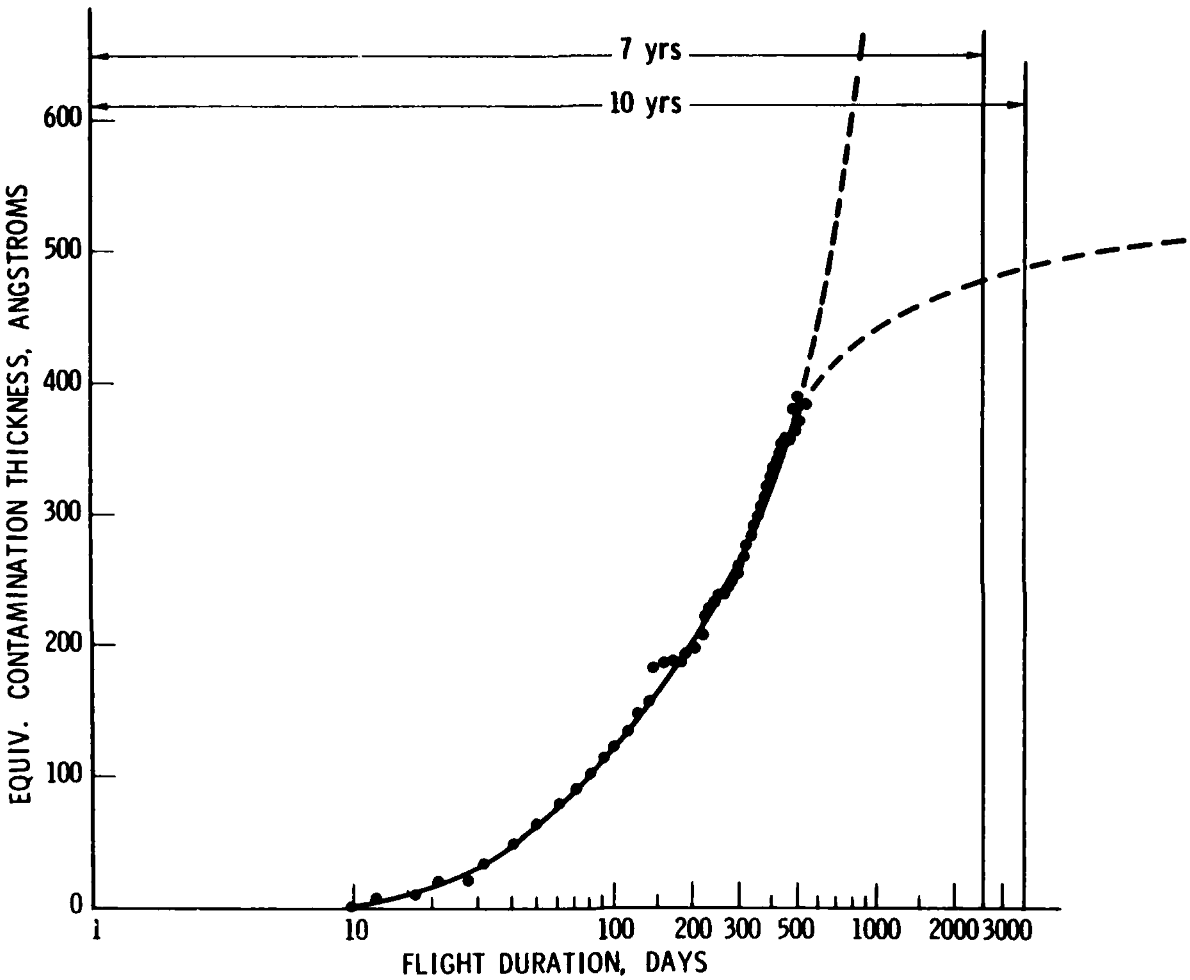

Fig. 14. Preliminary results from the Quartz Crystal Microbalance on the P78-2 satellite. The data show that a long time base is required in the data set if one wishes to extrapolate contaminant deposition over the design life of satellite systems now being planned.

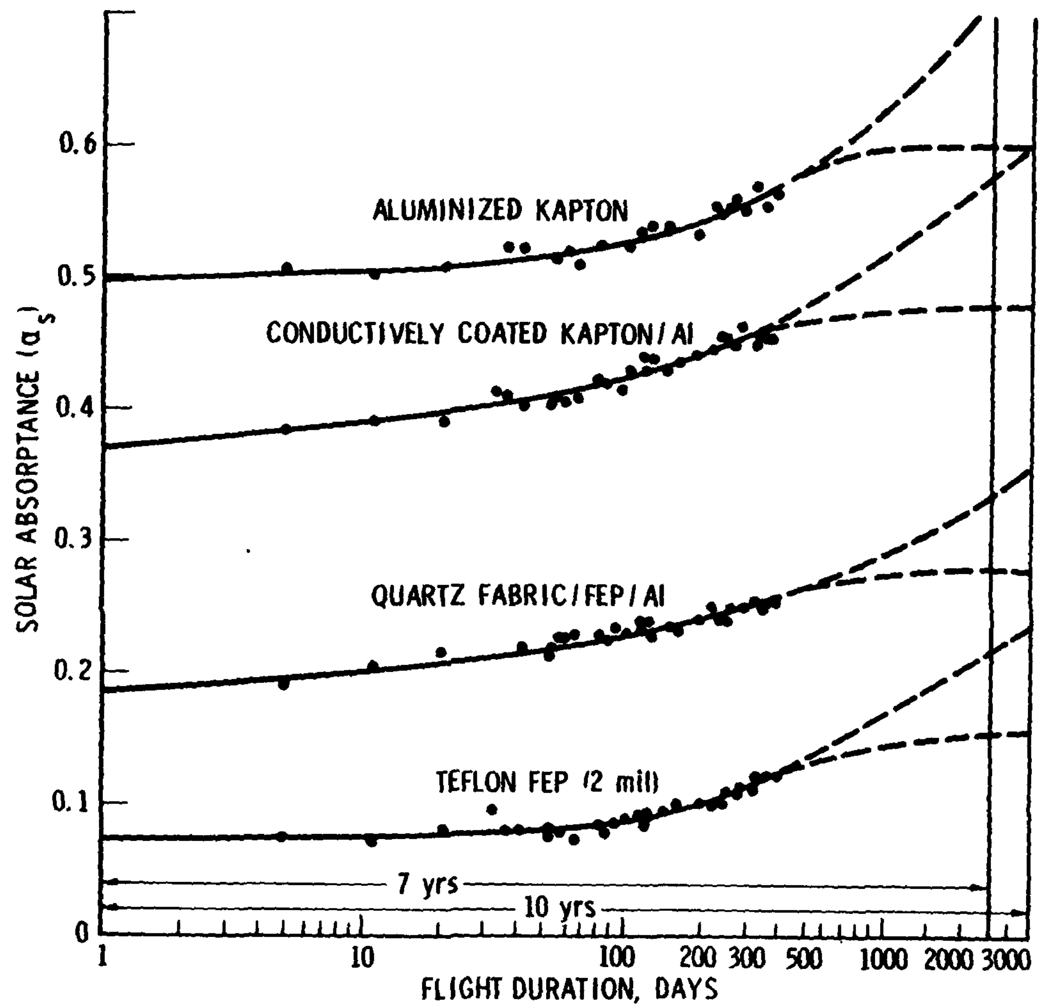

Fig. 15. Data, and conclusions, similar to that of Figure 14. This data is from the P78-2 Thermal Control Coatings experiment.

The data of figures 14 and 15 show the importance of obtaining very long term data on materials degradation in space. Satellite systems are projected which will require seven to ten year operational capability from the vehicle design. That will be difficult, if not impossible, if materials behavior during long term exposure to the space environment is not known quantitatively. Similar long term data are required for materials response to charging environments.

ANOMALY INVESTIGATIONS

Because the P78-2 vehicle makes measurements of a wide range of plasma parameters, from eV to MeV in both electrons and ions, and because it has been providing continuous data coverage, it has assisted in anomaly investigations. In one instance, a new spacecraft experienced the loss of one of a pair of redundant power distribution systems. Evaluation of the geometry of the system and the electrical configuration identified a possible failure mechanism which would be initiated by a momentary short to ground. Such a short to ground could be initiated by a discharge in an exposed cable. Data from the P78-2 vehicle showed that two days previous to the time of the anomaly charging conditions had existed, but were no longer severe at the time of the anomaly. There was an increase in the energetic electron fluxes at the P78-2 orbit.

In June of 1980, a Global Positioning System vehicle experienced an anomaly. The P78-2 data were analyzed to see if they could help in identifying the cause of the anomaly. GPS is in a lower, highly inclined orbit, and as such does not see the same environment as P78-2. However, one can extrapolate the P78-2 data and make good estimates on the GPS environment. The analysis showed that the SSPM, on June 10, had measured the highest potentials recorded since launch, > 10 kV on teflon, > 6 kV on the quartz cloth, and > 2 kV on the Kapton sample on the top (shadowed) instrument. No natural pulses were detected by the SC1-8B Pulse Analyzer. On the 12th, energetic electron fluxes (> 2 MeV) began to increase and, by the 13th, had reached the highest levels measured since launch. On the 13th, the Pulse Analyzer observed two discharges. On the 13, GPS experienced its anomaly. On the 14th, while energetic electron fluxes were still very high (private communication, J. B. Reagan, 1980), another discharge was observed by the Pulse Analyzer and the P78-2 had its first known naturally induced anomaly (a magnetometer mode change). During the period 11 June to 14 June, potentials measured by the SSPM remained much lower than they had been on the 10th. On the basis of the P78-2 data and other considerations, it was concluded that the GPS anomaly was probably due to a thick dielectric charging event caused by energetic electrons. Relatively scant attention has been paid to this portion of the SCATHA program, although some test results are available (refs. 16, 17). It is an area which the P78-2 environmental data set is very qualified to investigate.

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